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In the domain of motion perception, the implementation of a new pedestal paradigm and some critical subsidiary paradigms (interocular displays, stimulus superpositions with varying phases and directions, altrenating-feature stimuli, and attentional manipulations) enabled the measurement in isolation of the spatial and temporal characteristics of the three main human motion perception mechanisms (the so-called first-, second, and third-order systems). The first- and second-order systems, known previously, were now shown to exist in duplicate, having a primarily left eye and a primarily right eye computational branch. Additonally, a purely binocular (third-order) motion mechanism was discovered and measured.

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Visual Motion Perception and Visual Information Processing

PI: George Sperling, University of California, Irvine, CA

ABSTRACT

The reprints enclosed with this report describe experiments related to two main thrusts of the grant: motion perception and, more generally, visual information processing. In the domain of motion perception, the implementation of a new pedestal paradigm and some critical subsidiary paradigms (interocular displays, stimulus superpositions with varying phases and directions, alternating-feature stimuli, and attentional manipulations) enabled the measurement in isolation of the spatial and temporal characteristics of the three main human motion perception mechanisms (the so-called first-, second, and third-order systems). The first- and second-order systems, known previously, were now shown to exist in duplicate, having a primarily left eye and a primarily right eye computational branch. Additionally, a purely binocular (third-order) motion mechanism was discovered and measured. The functional architecture relating these five motion computations to human motion perception is described in Lu & Sperling (VisRes, 1995) and Lu and Sperling (Nature, 1995). In the domain of information processing, a computational theory of spatial attention that accounts for human performance in the major paradigms for studying attention was completed and published (Sperling & Weichselgartner, 1995). Other studies related to these issues are described in the appended publications.

OVERVIEW

The main activities throughout this grant have been carrying out the experimental research set forth in the proposal (1994), following up promising leads that developed in the course of this work, and preparing manuscripts for publication. A list of scientific articles and talks presented at scientific conferences is appended.

Knowing how humans perceive visual motion is of great potential importance in the design of visual displays. An understanding of the mechanisms of spatial visual attention would be useful to the designers of displays that present visual information from several sources to pilots and controllers who have to deal with information overload, and in the selection and training of personnel to view these displays. The accomplishments are described in the publications and technical reports; a list is appended followed by the publications in the order listed.

FACILITIES

The Human Information Processing Laboratory (HIPLab) is a highly versatile laboratory for conducting research in almost any area of vision or cognition as described in

previous progress reports.

PERSONNEL

Principle investigator. George Sperling, Professor of Psychology and Director of the Human Information Processing Laboratory. As projected in the original proposal, the PI devoted 20% time during 9 month academic year plus full time during three summer months.

Research Associate 1. Zhong-Lin Lu (full-time). Dr. Lu received his doctorate in low-temperature physics from NYU for projects related to neuromagnetic recording. He has changed fields and applied his considerable technical skills to projects in visual motion perception and to related mathematical and computational issues. He left in Fall, 1995, to assume a tenure-track faculty position at the Departments of Psychology and the Program in Neural, Informational and Behavioral Sciences, University of Southern California, Los Angeles.

Research Associate 2. Charles Chubb (part-time). Prof. Chubb, an experimental-theoretical psychologist was on leave from a regular faculty position at Rutgers University, New Brunswick, NJ. He worked on projects in motion and texture perception and theory and on a new kind of neural network for unsupervised visual pattern learning.

Research Associate 2. Eric Fredericksen. Dr. Fredericksen received his PhD in Computer Science at University of North Carolina and came to UCI in August 1996 from a previous postdoctoral position at McGill University in visual psychophysics with Robert Hess. So far, at his insistence, he has worked only on software development of a new real-time graphics package and has not participated in any psychophysical experiments.

Administrative assistant. Ms. Lauren Haines. Ms. Haines is supported 1/4 time on this grant and 1/4 time by the Department of Cognitive Sciences.

Graduate students

Eric Blaser. Mr. Blaser completed preliminary experiments for a project involving the measurement of spatial attention. In the preliminary experiments he has succeeded in measuring the spatial frequency response function of spatial visual attention, and he is now refining the paradigm to confirm these results and to complete his PhD thesis in Department of Cognitive Sciences at UCI.

Scott Richman. Mr. Richman is a student in the Institute for Mathematical Behavioral Sciences who has joined the laboratory. He worked initially on a project to measure the contributions of flicker to second-order motion, and he then worked on a project in texture perception.

6. PUBLICATIONS

These are listed in the attached pages, and describe in detail the research progress.

7. INTERACTIONS

These are enumerated in the lists of talks at conferences and at universities and institutes (on the following pages).

9. HONORS

1996. Society of Experimental Psychologists. *Howard Cosby Warren Medal, 1996.* The Society of Experimental Psychologists (SEP) is a national honorary society for experimental psychologists. The Warren Medal is the highest honor bestowed by SEP and is awarded annually for an outstanding research accomplishment. (Bronze plaque, citation, $500.)

George Sperling: HIP Lab Publications, 1994-97

1994 Solomon, Joshua A., and Sperling, George. (1994). Full-wave and half-wave rectification in 2nd-order motion perception. *Vision Research, 34 (17),* 2239-2257.

1994 Sperling, G., and Dosher, B., A. (1994). Depth from motion. In *Early Vision and Beyond.* T. V. Papathomas, Ed. Cambridge, MA: MIT Press, 1994. Pp. 133-142.

1994 Sperling, G., Chubb, C., Solomon, J. A., and Lu, Z-L. (1994). Fullwave and halfwave processes in second order motion and texture. In *Higher-order processing in the visual system.* Chichester, UK: Wiley (Ciba Foundation Symposium, 184). Pp. 287-303. Discussion: Pp. 303-308.

1994 Sperling, G., and Lu, Z-L. (1994). Immunity to pedestals distinguishes motion-energy from feature-tracking motion-perception mechanisms. *Investigative Ophthalmology and Visual Science, ARVO Supplement,* 1994, *35, No. 4,* 1390. (Abstract)

1994 Sperling, G. (1994). Second-order perception. *Investigative Ophthalmology and Visual Science, ARVO Supplement,* 1994, *35, No. 4,* 1477. (Abstract)

1994 Lu, Z-L. and Sperling, G. (1994). Deriving the dimensions of texture perception from metameric texture matches. *Investigative Ophthalmology and Visual Science, ARVO Supplement,* 1994, *35, No. 4,* 2161. (Abstract)

1994 Sperling, G., Chubb, C., Solomon, J. A., and Lu, Z-L. (1994). Visual preprocessing: First- and second-order processes in the perception of motion and texture. In *J. M. Zurada, R. J. Marks II, Charles J. Robinson (Eds.), Computational Intelligence: Imitating Life.* IEEE Press, The Institute of Electrical and Electronics Engineers, Inc. New York, 1994. Pp. 223-236.

1994 Shih, Shui-i and Sperling, G. (1994). Using cluster analysis to discover and characterize covert strategies. *Psychological Science, 5,* 175-178.

1994 Werkhoven, Peter, Sperling, George, and Chubb, Charles. (1994). Perception of apparent motion between dissimilar gratings: Spatiotemporal properties. *Vision Research, 34,* 2741-2759.

1994 Chubb, C., McGowan, J., Sperling, G., and Werkhoven, P. (1994). Non-Fourier motion analysis. In *Higher-order processing in the visual system.* Chichester, UK: Wiley (Ciba Foundation Symposium, 184). Pp. 193-205. Discussion: Pp. 206-210.

1994 Sperling, G. and Shih, S. (1994). Mechanisms of feature-based attentional selection in visual search. *Bulletin of the Psychonomic Society,* 1994, *32,* 53. (Abstract)

1995 Solomon, J. A., and Sperling, G. (1995). 1st- and 2nd-order motion and texture resolution in central and peripheral vision. *Vision Research, 35,* 59-64.

1995 Sutter, Anne, Sperling, George, and Chubb, Charles. (1995). Measuring the spatial frequency selectivity of second-order texture mechanisms. *Vision Research, 35,* 915-924.

1995 Lu, Z-L. and Sperling, G. (1995). Drastically different saturation for luminance motion versus texture-contrast motion. *Investigative Ophthalmology and Visual Science, ARVO Supplement,* 1995, *36, No. 4,* S395. (Abstract)

1995 Sperling, G. and Lu, Z-L. (1995). Attention affects the perceived direction of visual motion. *Investigative Ophthalmology and Visual Science, ARVO Supplement,* 1995, *36, No. 4,* S856. (Abstract)

1995 Shih, S., and Sperling, G. (1995). A model of selective attention in early visual processing. *Investigative Ophthalmology and Visual Science, ARVO Supplement,* 1995, *36, No. 4,* S857. (Abstract)

1995 Sperling, George, and Weichselgartner, Erich. (1995). Episodic theory of the dynamics of spatial attention. *Psychological Review, 102 (3),* 503-532.

1995 Lu, Zhong-Lin and Sperling, George. (1995). The functional architecture of human visual motion perception. *Vision Research, 35,* 2697-2722.

1995 Lu, Zhong-Lin and Sperling, George. (1995). Attention-generated apparent motion. *Nature, 377,* 237-239.

1995 Sperling, G. and Lu, Zhong-Lin. (1995). Visual Attention Operates Via a Salience Map. In *Program. 36th Annual Meeting. The Psychonomic Society.* Psychonomic Society, Inc: Austin, Texas. 58. (Abstract)

1996 Lu, Zhong-Lin and Sperling, George. (1996). Three systems for visual motion perception. *Current Directions in Psychological Science, 1996, 5 (2), 44-53.*

1996 Lu, Zhong-Lin and Sperling, George. (1996). 2nd-order illusions: Mach bands, Chevreul, and Craik-O-Brien-Cornsweet. *Vision Research, 36, 559-572.*

1996 Shih, Shui-i and Sperling, G. (1996). Is there feature-based attentional selection in visual search? *Journal of Experimental Psychology: Human Perception and Performance, 22 (3),* 758-779.

1996 Chubb, C., Lu, Z-L., and Sperling, G. (1996). Algorithm for extracting structure in natural images yields simple cell-like receptive fields. *Investigative Ophthalmology and Visual Science, ARVO Supplement, 1996, 37, No. 3,* S517. (Abstract)

1996 Lu, Z-L., and Sperling, G. (1996). The Lincoln Picture nonproblem. *Investigative Ophthalmology and Visual Science, ARVO Supplement, 1996, 37, No. 3,* S732. (Abstract)

1996 Richman, S., Lu, Z-L., and Sperling, G. (1996). Flicker motion. *Investigative Ophthalmology and Visual Science, ARVO Supplement, 1996, 37, No. 3,* S746. (Abstract)

1996 Sperling, G, and Lu, Z-L. (1996). Second-order reversed-phi reveals two mechanisms: Second-order motion energy and third-order feature salience. *Investigative Ophthalmology and Visual Science, ARVO Supplement, 1996, 37, No. 3,* S900. (Abstract)

1996 Sperling, G., Lu, Z-L, and Chubb, C. (1996). First principles of second-order perception. *1996 SID International Symposium, Digest of Technical Papers* Santa Ana, CA, 92705-5421: Society for Information Display. 961-964.

1996 Shih, S. and Sperling, G. (1996). The time course of covert visual attention shift. *International Journal of Psychology,* 1996, *31,* (3/4), 109. (Abstract)

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1996 Sperling, G. (1996). New theories of motion perception. *International Journal of Psychology,* 1996, *31,* (3/4), 362. (Abstract)

1996 Sperling, G. & Lu, Z.-L. (1996). The functional architecture of visual motion perception. *International Journal of Psychology,* 1996, *31,* (3/4), 362. (Abstract)

1996 Lu, Zhong-Lin and Sperling, George. (1996). Contrast gain control in first- and second-order motion perception. *Journal of the Optical Society of America A: Optics and Image Science, 13,* 2305-2318.

1997 Lu, Z-L, Sperling, G., and Beck, J. R. (1997). Selective adaptation of three motion systems. *Investigative Ophthalmology and Visual Science, 38 (4),* ARVO Abstract Book--Part 1, S237. (Abstract)

1997 Sperling, G, and Lu, Z-L. (1997). Proving the independence of first- and second-order motion systems. *Investigative Ophthalmology and Visual Science, 38 (4),* ARVO Abstract Book--Part 1, S237. (Abstract)

1997 Chubb, C., Lu, Z.-L., and Sperling, G. (1997). Statistically certified unsupervised learning. *Investigative Ophthalmology and Visual Science, 38 (4),* ARVO Abstract Book--Part 1, S257. (Abstract)

1997 Blaser, E., Sperling, G., and Lu, Z.-L. (1997). Measuring the spatial resolution of visual attention. *Investigative Ophthalmology and Visual Science, 38 (4),* ARVO Abstract Book--Part 2, S687. (Abstract)

1997 Sperling, G. (1997). The goal of theory in experimental psychology. In R. L. Solso (Ed.,) *Mind and Brain Sciences in the 21st Century.* Cambridge, MA: MIT Press. Pp. 253-264.

1997 Chubb, Charles, Lu, Zhong-Lin, and Sperling, George. (1997). Structure detection: A statistically certified unsupervised learning procedure. *Vision Research (Special Issue: The Vision of Natural and Complex Images), 37,* 3343-3365.

1997 Sperling, G., and Shih, S. (1997). Measuring and modeling selective attention in early visual processing. *Abstracts of the Psychonomic Society, 2,* 18. (Abstract)

George Sperling
Talks at Symposia and Meetings of Professional Societies, 1994-97

† Indicates an invited address. * Indicates an abstract of talk was published.

1994 Solomon, Joshua A., and Sperling, George. (1994). Full-wave and half-wave rectification in 2nd-order motion perception. *Vision Research, 34 (17),* 2239-2257.

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George Sperling
Invited Lectures at Universities and Institutes, 1994-97

1994 Ohio State University, Columbus, College of Optometry. May 9, 1994:
Low-Vision Seminar. *Optimal Images and Optimal Perception.*
Distinguished Speakers Series. *Second-Order Perception.*

1994 University of Goettingen, Drittes Physikalisches Institut, University Lecture. July 22, 1994. *Computational Principles of Visual Perceptual Processing.*

1994 Max Planck Institute, Tuebingen, Germany. July 25, 1994. *Visual Preprocessing.*

1994 University of Pennsylvania, The Institute for Research in Cognitive Science, Cctober 7, 1994. *Computational Principles of Visual Perceptual Processing.*

1995 California Institute of Technology, Computational and Neurals Systems Group, Beckman Center, January 9, 1995. *Computational Principles of Visual Preprocessing.*

1996 Marschack Interdisciplinary Colloquium on Mathematics in the Behavioral Sciences, sponsored by the Anderson School and the Department of Economics, with support from the Anderson School Dean, the School of Public Policy and Social Research Dean, the Blum Kovler Foundation, and the Sidney Stern Memorial Trust. University of California at Los Angeles, Los Angeles, CA, March 1, 1996. *The Economics of Attention, and Other Tales.*

1996 Dedication Ceremony for the new Cognitive and Neural Systems Building, Boston University, Boston, Massachusetts, April 19, 1996. *Atoms of the Mind.*

1996 Sensation and Perception Lunch Group, University of California, Irvine, January 10, 1996.
George Sperling and Zhong-Lin Lu: *Attentional Motion.*
Erik Blaser and George Sperling: *Semantic Motion.*

1996 Sensation and Perception Lunch Group, University of California, Irvine, May 29, 1996. *Atoms of the Mind* (and) *The Goal of Theory in Experimental Psychology.*

1996 Sydney Area Vision Group, University of New South Wales, Sydney, Australia, July 19, 1996. *Computational Principles of Early Visual Processing*

1996 Department of Psychology, University of Western Sydney, Macarthur, Campbelltown NSW 2560 Australia, July 29, 1996.
Special joint colloquium: Computer Sciences and Psychology. *Computational Principles of Early Visual Processing.*
Psychology Colloquium. *Atoms of the Mind: An Historical Overview of Theories of Attention.*

1996 Psychology Colloquium, University of New South Wales, Sydney, Australia, July 31, 1996. *Atoms of the Mind: An Historical Overview of Theories of Attention.*

1996 Psychology Colloquium, University of Western Australia, Nedlands Australia.

August 1, 1996. *Atoms of the Mind: An Historical Overview of Theories of Attention.*

August 2, 1996. Vision Discussion Group: Visual Preprocessing: Modeling the Initial Stages of Human Visual Perception.

1996 Biology Colloquium, Australian National University, Research School of Biological Sciences, Center for Visual Sciences, Canberra, Australia, August 6, 1996. *Computational Principles of Early Visual Processing: From Adaptation to Attention.*

1996 California Institute of Technology, Sloan Center for Theoretical Neurobiology and the Computation and Neural Systems program, Sloan Center Seminar October 7, 1996. *A Functional Architecture for Visual Motion Perception and Spatial Attention.*

1996 University of California, Irvine, Department of Psychobiology, Departmental Colloquium, October 10, 1996. *Deriving a Functional Architecture for Visual Motion Perception and Spatial Attention.*

1997 Max Planck Institute, Munich, Germany. April 2, 1997. *Computational Review of Early Visual Processing.*

1997 Max Planck Institute, Tuebingen, Germany. April 3, 1997. *How to Experimentally Isolate Three Systems of Visual Motion Perception.*

1997 University of Houston, Houston, Texas, December 6, 1997.

(1) College of Optometry, Seminar. *The Orders of Visual Motion--Techniques for Creating Pure Stimuli.*

(2) Institute of Cognitive Sciences Distinguished Speakers Series. *Deriving a Function Architecture for Visual Motion Perception.*